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STRATEGIC MATERIALS

ABSTRACT

The Strategic Materials industry contributes to economic prosperity and military strength because its products enable performance advantages on a national scale. Heavily reliant on technological innovation to remain competitive, this diverse industry includes a broad range of products from metals to nanoscale materials. Research and development and the ability to respond flexibly to promising discoveries are essential to maintaining a competitive advantage within the commercial and defense sectors in an increasingly globalized world. Collaborative efforts between government, industry and academia push the edges of scientific and technological possibility in search of new materials and applications that will revolutionize the way Americans live and work.

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THE STRATEGIC MATERIALS INDUSTRY

Introduction

A nation's competitive advantage flows from its ability to innovate and to respond flexibly to a rapidly changing global environment. On the economic side, economies with the most agile businesses and rational government policies have the greatest resilience and the greatest potential for sustained growth. In the military arena, the innovative use of technology often gives a country an edge over its enemies and provides security at home. The link between economic strength and military power is critically important, requiring a balance between the demands of the market and national security. Failure to maintain that balance can sap the vitality and dynamism of the economy or undermine the nation's ability to defend its territory, people and institutions. The United States has consistently demonstrated a remarkable ability to achieve this balance through policies that encourage innovation and a reliance on technology that combine to sustain competitive advantage over time.

This study examines how one sector of industry – the strategic materials industry – contributes to national security and national competitive advantage. This diverse industry produces materials and products important to overall economic growth and prosperity, and critical in many instances to national defense. In the last century, strategic materials meant primarily metals, rubber and a variety of natural and synthetic fibers. At the beginning of the 21st century, however, strategic materials encompass a wide variety of materials and products from traditional metals to molecular scale computing devices that have or potentially will have defense applications. In the past, sheer volume of materials production and its associated heavy industrial output could ensure economic and military strength. Today, volume is generally less important than the properties and capabilities a material brings to its application. Materials producers and manufacturers must look for a competitive edge through research and development and the use of technology, and they must do so in the context of a global economy that permits easy flow of goods, services and information across increasingly less visible national boundaries.

In preparing this study, the Seminar visited a number of laboratories, universities and companies in the U.S., Canada, Germany, Austria and the United Kingdom, and spoke to several industry and government representatives. The companies are primarily manufacturers of component products used in a variety of military and commercial applications. The universities are conducting research into new materials, applications and manufacturing processes, often in collaboration with government and/or industry, and always with a view towards the potential marketability of the fruits of the research. Government-funded laboratories are conducting research into new military applications, but are ever mindful of findings that may have commercial value. In North America and Europe, governments are finding creative means to drive the development of new technologies, materials, applications and products to ensure economic prosperity. In the United States, the government is also using its national defense requirements to maintain a viable strategic materials industry.

Defining a Strategic Materials Industry

The concept of a strategic materials industry is an artificial construct to its components – only a few of the companies visited saw themselves as part of the materials industry and there is no discrete trade group representing a strategic materials industry. This industry is more accurately an aggregation of large and small companies that produce a broad range of materials, components and finished products working in conjunction with researchers looking for the next technological advance in materials and their applications. For the purposes of this study, the Seminar opted to include traditional and newer materials as well as promising new areas of research that may one day deliver breakthrough products for defense or broader commercial application: steel, aluminum, titanium, polymer and metal matrix composites, ceramics, "smart", nano- and micro-materials and technology; molecular manufacturing and biomimetics. An assessment of a material's strategic importance and its projected contribution to the national economy and military power within the next 15 years were the primary selection criteria.

The number of materials considered strategic is nearly limitless if expanded to encompass every defense, economic or national security requirement. The strategic significance of a material can change over time as these requirements change. A material's defense applications can confer strategic significance when military might is an essential element of national power. The idea that strategic materials are "substances used to make things necessary for fighting a war" is overly broad because scarcity and access seem relevant. Otherwise, most anything could be labeled "strategic," since war machines use a spectrum of materiel from toilet paper to precision guided munitions. It is difficult to determine which materials are necessary for military success because both demand and supply are variable, and, in the worst cases, extremely so.

One useful distinction between materials is based on availability: "a material is critical if you need it, but strategic if you need it and have trouble getting it."[1] By inference, any material with constrained availability is strategic. However, scope is also relevant; materials such as steel are so pervasive in defense applications and infrastructure that they are essential, even if not scarce. When an essential material becomes ubiquitous, the assurance of its supply gains strategic significance. Hence, the reason both the Department of Defense (DoD) and the U.S. Geological Survey monitor trends in the steel industry even though supply is anything but constrained.

Whether a material is used solely in defense applications or more broadly in the commercial economy is another aspect to consider in determining a material's strategic significance. To some degree, this is a distinction without a difference since materials are generally useful in both the defense and non-defense sectors. Excluding materials without military application from the strategic realm is senseless if the lack of those materials stymies an economy, thereby weakening society's ability to support its military. Therefore, materials attain strategic significance when they are essential to a nation's economic and military might and when their availability is constrained or nearly so with respect to demand from defense or overall needs.

Perhaps the key test of a material's strategic significance is the capabilities the material enables – if the material adds a significant performance advantage in some key application, it gains strategic relevance. It is this perspective which demands the inclusion in this study of smart-, nano- and micro- scale materials, and their associated manufacturing technology. Though mostly still in the research and development phase,

these potential industries may, in the near future, enable revolutionary capabilities in defense or economic applications. It is this potential that spurs governments, universities and companies around the world to fund this research to gain a competitive advantage in the near future.

No universally agreed upon definition for a strategic material exists; even within the entities that process, procure, and/or use them. Despite the diversity of opinion, several recurring themes about the nature of a strategic material consistently arose during the course of the Industry Study. In order to be considered strategic, materials must meet the following criteria: be essential to defense, and, while replaceable in specific applications, have no universally suitable substitute; contribute to the overall economy, regardless of defense applications; and enable breakthrough advances in defense or commercial applications.

Current Conditions

There is a surprising degree of commonality among the diverse segments of the strategic materials industry. The common trends originate in the competitive free market environment that forces materials producers to anticipate customer requirements and to respond flexibly in order to survive. Information technology coupled with open markets and liberalized trade enables both global awareness of market conditions and universal access to materials, services and customers. These forces are norming business practices throughout the industry, shaping the industry's emerging sectors and breaking down traditional vertically integrated corporate structures. Additionally, the traditional distinction between materials science and manufacturing is disappearing as research focuses not only on materials and their applications, but also new ways to create, manufacture or produce those materials for defense and commercial applications. This is occurring not only in U.S. industry, but in Canada, Europe and Japan as well.

The components of the strategic materials industry are generally unrestrained in their ability to access natural resources. Transportation is relatively cheap, enabling manufacturers to look abroad for source materials. The U.S. is dependent on foreign supplies of ores and semi-refined resources for certain strategic materials because it produces fewer than it uses in all categories. In some cases, the U.S. lacks indigenous deposits (e.g., bauxite for aluminum). In other cases, American companies choose not to exploit them for economic or environmental reasons (e.g., titanium dioxide ore). European and Canadian manufacturers are also dependent on foreign sources in many instances and benefit from the low cost of transportation. At least one company in Europe said it did not need to be close to supplies of raw materials, but preferred to be closer to its customers.

The U.S. is also dependent on foreign suppliers for finished and semi-finished strategic materials because it produces less than it consumes (e.g., steel and semi-finished titanium sponge). Access to resources is generally unconstrained, though certain important materials are subject to short-term manipulation or disruption due to political instability (e.g., tantalum, cobalt). Manipulation of prices tends to spur either governmental intervention or development of new sources of supply or both. Large multi-national corporations also control significant amounts of offshore resources, such as Alcoa's bauxite and alumina holdings. Fortunately, most multi-nationals generally have a significant financial stake in supplying U.S. markets, and many are U.S. based.

The DoD began selling off its reserve stockpile of strategic materials well over a decade ago. Recurring operating costs and an assessment of minimal risk of supply interruption were two of the reasons for the decision to sell off the stockpile. Some of the stockpile was unusable in its stockpiled form, either due to deterioration or to the requirement for additional processing, raising the question as to whether stockpiling is a feasible hedge to supply interruptions even under the best of conditions.

American industry produces significant amounts of strategic materials even if it produces less than the economy consumes. DoD uses a statistically insignificant portion of the strategic material resources available to the U.S., in no case more than 10% overall of U.S. based production, though certain niche items may be have higher percentages as defense-unique applications exist, such as the steel alloys used for submarine hull construction. DoD also purchases materials and products manufactured abroad, partly for political reasons, but also for reasons of supply. Canadian and European firms rely greatly on their sales to DoD, albeit usually as sub-contractors. While strategic materials are essential to the production and maintenance of defense hardware and infrastructure, DoD is a marginal player in the overall materials market and therefore has limited influence. DoD unique needs require financial incentives to get an industry response – it is simply too small a customer to sway the market without providing financial incentives.

Like most developed economies, the U.S. is generally non-competitive in the global marketplace in low value added, labor-intensive industries, because its wage scale is much higher than in developing nations. The U.S. is very competitive in highly capitalized, technology-intensive industries. Its advantages come from its easy access to capital and a stable economy that encourages investment. U.S. worker productivity is high. Recent significant gains in productivity are in part due to industry's willingness to capitalize workers with technologically advanced equipment. Canadian and European companies are similarly constrained in their ability to compete in labor-intensive industries. Like U.S. firms, they are seeking a competitive advantage through creation of intellectual property that yields technological innovation.

Strategic materials producers compete in two basic ways – either in the commodities market or in specialty/niche markets. In both cases, the U.S. market is among the world's most open, but is perceived as protectionist in many segments because of the periodic use of tariffs. Regardless of perception, the reality is that U.S. industries have access to any freely traded material even if outside interests skew the prices. Canadian firms benefit greatly from the provisions of the North America Free Trade Agreement (NAFTA), but often still encounter problems, including restrictions on the flow of sensitive technologies and information. European firms supplying DoD also noted export controls as a barrier to free entry into the U.S. market.

The relatively open U.S. market forces commodities producers (primarily basic metals and fiberglass) to deliver their products at a globally competitive price. Producers differentiate themselves to customers by ease of doing business, since the market dictates manufacturers reliably deliver competitively priced materials "just in time." Because this sector operates on slim margins, it spends relatively little on research and development, thereby limiting its potential for growth through innovation.

Innovation is essential to niche producers, who are more willing, but often less able to afford extensive research. Niche markets are often more profitable by percentage than scale driven counterparts, but also more volatile because success or failure often

hinges on the results of applied research. Much of the emerging and developing segment of the strategic materials industry sustains itself in niche markets. Defense is a driving force in many of these markets, because DoD demands performance frequently unavailable from common materials and is willing to pay for them both through funding research and paying higher prices to get increased performance.

Some of the newer segments of the materials industry are already leaving the research labs. Micro-electro-mechanical systems (MEMS) are widely used in airbag sensing systems and ink jet print heads. While nano-scale materials are not yet routinely assembled into nano-scale machines, they are being used to reinforce polymer composites processing and in the textile industry among many other applications.

Ceramics and composites manufacturers also serve niche markets because their products have useful and profitable applications, but have specific limitations in performance, price, or both which prevent widespread adoption. In certain applications, such as prosthetic surgery, these materials deliver performance that has no suitable substitute. In some cases, the limiting factor in more widespread use is not in the material itself. For example, composites are a proven technology in small boat applications and are structurally suitable for use in larger vessels. Thus far, composite use remains confined to small vessels while planners wrestle with safety concerns and builders avoid retraining and retooling expenses for their workforces. For any new material, the biggest barriers to market penetration can be economic and perceptual. As a result, several firms, both domestic and foreign, said they often keep new technologies on the shelf until a customer indicates a requirement for a particular application. In most cases, the customer pays the cost of investment in the new technology.

Challenges

The strategic materials industry confronts some significant and vexing economic issues, including market globalization, high costs of production, research and development funding, and environmental concerns. The industry's ability to deal successfully with these issues is key to the long-term viability of certain segments of the industry. Failure to address these issues will diminish competitiveness and strangle innovation and technological advancement.

Globalization is rapidly eroding the boundaries between foreign and domestic trade, making autarky an unachievable aspiration for any nation. The American tendency toward isolationism periodically inspires waves of sentiment to reduce U.S. dependence on foreign resources. This sentiment is out of step with the reality of international business, the physical location of exploitable raw materials and the rapid flow of information. Globalization's effects on industry are much more basic than the demise of autarky. The availability of cheap transportation and instant access to information means strategic materials producers have to compete with everyone, everywhere, at any time. Industry is dependent on governments to try to ensure that the marketplace is a level playing field, a process that leads to barriers on both sides of the Atlantic. The proliferation of suppliers in the U.S. marketplace keeps prices down, particularly for material commodities where the only distinction is price. In order to stay profitable, producers must sell at market price and control production costs.

The realities of the U.S. economy – expensive but productive labor, a relatively open market, pervasive use of information technology and readily available capital and

material resources – set the framework for industry to manage costs. To be successful, industry must compete where it is strong and abandon processes that others can execute more efficiently. American strategic materials producers are most competitive in highly capitalized, highly automated, technologically advanced sectors. To stay competitive in such an environment, industry must innovate through research and convince the capital market that it can provide a significant return on investment. The requirement for agility and flexibility in market decisions is critical and applies to materials producers and users in North America and Europe.

Industry's dependence on technological innovation conflicts with market pressure for profit because innovation requires research and development but the market demands quick return on investment. Because basic research often has a slow return, industry prefers applied research and development. Industry is fortunate that academia and government have substantial investments in basic research that industry can leverage. However, the roles and relationships between government, academia, and industry are changing. Government, which historically underwrote a substantial percentage of basic research on a somewhat altruistic basis, is now interested in both harvesting the fruits of its research as well as focusing more on applied research. Academia is transitioning to more entrepreneurial models to profit from the commercialization of materials technology. The intellectual property business has become more competitive, challenging industry to find the right spending level and the appropriate means to share the profits of intellectual property with its research partners. The availability of adequate human resources to develop that intellectual property is also a concern confronting the materials industry globally.

Environmental matters are an increasingly important concern to industry on a global basis. Although specifics vary by country, government regulations and international agreements prescribe recycling goals and emissions limitations and ban the use of certain materials and industrial processes. In some cases, industries gain a competitive advantage by operating in nations with less stringent environmental standards. Environmental regulations have also spurred technological achievements that make production not only cleaner, but also often more efficient in the long run. Environmental concerns also play a role in determining the selection of a material for a specific application. Recycling targets have kept polymer composites out of some automotive applications because they are difficult to reprocess, but these same composites may gain acceptance in infrastructure applications because of their resistance to environmental degradation. Industry must integrate environmental challenges and opportunities into its strategic planning processes.

Outlook

Continuing success in the materials industry depends heavily on aggressive research and development into new materials, applications and processes for rapid commercialization to produce competitive advantage both economically and militarily. Many segments of the industry are prepared to take advantage of technology that improves their productivity and competitiveness and they are willing to dedicate their own resources towards that effort. Firms in those segments have flexible strategic planning processes to help them identify their core competencies and future growth areas, and are prepared to act upon those plans. Even in the mature segment of the industry

significant potential remains for improved competitiveness through technology, the development of new, more versatile products and innovative applications.

Steel, aluminum and titanium manufacturers understand the need to apply technology, even though results are mixed across the sectors. The steel industry is in the midst of a comprehensive 5-year plan to increase sales and create new applications for its products. This co-operative effort is unprecedented and could serve as a model for successful capital-intensive industries in the future.[2] Alcoa, the American based international aluminum company, achieved market dominance through global influence and leadership to eliminate global excess capacity problems that haunt the steel industry today. Titanium producers have financed research into less energy-intensive production processes in order to lower costs and improve competition with steel and aluminum.

As globalization attracts lower cost foreign producers into the metal markets, it is increasingly difficult for U.S. metal producers to remain competitive even as they develop more specialized and versatile products. The drive to match lower cost producers diminishes resources available for developing new products. China is likely to challenge Alcoa's leadership role over the next five years if it brings an expected 3 million tons of new capacity to the market[3]. This development could create an overcapacity problem in the aluminum sector similar to that currently found in the steel sector. Domestic metal production is generally sufficient to meet market demand in many sectors, and global supply is more than adequate to fill gaps in domestic supply. The ready availability of metals on the global market raises a question about their strategic value and argues against measures to protect domestic production for national security reasons.

The composites industry is on the verge of technological breakthroughs in manufacturing that should improve its global competitiveness as well as its attractiveness as a substitute for metal in a variety of applications. Cost is the largest constraint on the expanded use of composite materials, because development and processing is highly labor intensive. More efficient, automated processing methods and a growing reliance on computer modeling and design should help drive down costs. The most extensive use of advanced fiber polymer composites (carbon fiber-based composites) is in the aerospace/aircraft and sporting goods sectors, which are willing to pay for the performance advantages composites bring. Industry analysts project rapid growth in the use of carbon fibers in the industrial sector over the next five years, with consumption more than tripling from the 1995 level of 3,500 tons to 14,000 tons (compared with just under 5,000 tons in the sporting goods sector in 2005).[4] The basis for this growth projection is an expected increase in the use of carbon-fiber composites in construction applications driven by the need to upgrade aging civil infrastructure in the U.S. and Europe.

Similar growth should occur in the metal composites sector. Business Communications Company projects this market will rise to 4.9 million kg valued at $173.3 million during the next five years, corresponding to a 14.1% AAGR (average annualized growth rate) from 1999 through 2004. Expansion of current and on-the-verge applications in the ground transportation, electronics/thermal management and industrial markets should drive this growth rate.[5]

Innovative multidisciplinary approaches to research and development and advances in information technology enable progress towards materials and applications

that may make science fiction into reality. The new fields of nanoscience, MEMs, biomimetics and "smart" materials are on the leading edge of technological and scientific innovation and should yield results with application across many areas of technological and scientific endeavor. Materials with reproducible properties, biomimetic-based sensors, DNA protein, and self-repairing systems are all visions that will one day certainly be reality. Basic and applied research in these areas could dramatically change electronics and computational devices and may yield advantages to a variety of multifunctional materials.[6]

Scientists predict that research in nanotechnology will eventually lead to revolutionary scientific breakthroughs. The intense interest in nanostructures stems from the idea that they may boast superior electrical, chemical, mechanical or optical properties.[7] MEMS promise to revolutionize nearly every product category by bringing together silicon-based microelectronics with micro-machining technology, thereby, making possible the realization of complete systems-on-a-chip.[8] A report issued by the MEMS Industry Group, shows the nation's MEMS industry is growing at an exponential rate, creating scores of new businesses, increasing employment, and diversifying applications into new industry sectors. Today, estimates place the number of MEMS devices in the U.S. at just fewer than two per person. By 2004, that number should grow to nearly five per person-- an annual growth rate of 45%.[9]

The accelerating convergence between materials science and manufacturing, fostered by ever-improving information technology and intellectual capital will drive the next technological revolution. The new materials and their production processes – whether bottom-up or top-down – will be more versatile than those that exist today and will enable the government and the private sector entities that produce them to achieve the next window of competitive advantage. That advantage will contribute to economic growth and generate resources to fund national security requirements for the near future.

The Role of Government

Recent U.S. National Security Strategies stress the importance of technology as an impetus to sustained economic growth and a key component of military strength. The U.S. is not alone in pursuing technology for economic growth, the world's advanced and advancing economies all understand the critical link between technology and economic prosperity. In the U.S., the federal government works collaboratively with academia and industry to push development of advanced technologies. In Canada, while the federal government plays a role, innovative provincial level programs such as that found in Ontario are matching money, researchers and industry. In Europe, the European Union is funding research while some universities are turning entrepreneurial in their own right. National strategies vary according to cultural differences and economic interests. These also affect how much a government spends on the search for technology and where it is spent. Few other nations reach out as broadly for technological dominance as the U.S. does, and none is as financially committed to defense technology.

The economic benefit of being first to market ensures global competition for technology development leadership. The question becomes whether the current U.S. R&D policies and roles are sufficient to maintain technological innovation and competitive advantage for strategic materials in the future. Efforts to achieve competitive advantage in both the defense and non-defense sectors were evident in industry study

research in the United States, Canada, the United Kingdom, Austria, and Germany. All firms and universities visited discussed their view of the appropriate role of government (including European Union) as either a direct supporter of research and development, as a promoter of technology transfer, or as the basic guarantor of an adequate base of knowledge workers and centers of excellence within academia.

The U.S. system of support for innovation has evolved over the last 20 years from one based largely on meeting defense needs to a wide-ranging effort to secure competitive advantage for the U.S. economy more broadly. Legislation enacted during this period enabled government-operated federal laboratories to enter into cooperative research and development agreements (CRADAs); loosened restrictions of antitrust laws to encourage U.S. firms to undertake joint long-term research; facilitated industry-university cooperation and provided a tax credit for all company payments to universities for basic research; allowed the vesting of title to inventions funded by the government in universities and small businesses; and created the Small Business Innovation Research (SBIR) program to strengthen the role of small firms in federally supported research and development. The synergy created by changes to collaborative efforts among industry, government, and non-profit institutions is evident in all areas of materials science.

In the U.S. model, government, academia and industry play different roles in seeding technology – contributions vary depending on the specific application and according to their strengths and interests. In certain areas, such as defense, government pushes technology development. The ambition to achieve military performance breakthroughs and the ability and willingness to fund the required technology is a key competitive advantage for the U.S. Less generously funded defense establishments, such as in Canada and Europe, must pull technology from industry or enter consortia to achieve sufficient critical mass to spur large-scale advances. On the commercial side, the U.S. Government tends to a more passive role in the development of new technology, preferring to leave industry to innovate on its own. Europeans have also used consortia effectively in the commercial marketplace in order to compete more successfully with the U.S. In the final analysis, the U.S., Canadian and European governments have a stake in ensuring innovation occurs in all sectors in order to remain competitive.

<u>Government Support of University Excellence.</u> The relationship between government, industry, and universities in research and development has evolved in recent years. Universities have increased their role through the emergence of an entrepreneurial approach that fosters direct involvement with the commercialization of research activities. In the U.S., several laws facilitate industry-university cooperation and this collaboration provides industry with a new source of research and development in a time of increased global competition. Uniquely situated as a bridge between industry and government, universities can provide expertise and a long-term research timeframe where no single industry can bear the cost. Providing universities with patent title has also encouraged licensing to industry where technology can be manufactured or utilized, thereby creating a financial return for the academic institution.[10] Between 1991 and 1996, license revenues for the top 35 "entrepreneurial universities" in the U.S. grew from $130 million to $365 million or at an annual average growth rate of 23 percent.[11]

One example in the U.S. strategic materials industry is the University of Delaware's Center for Composite Materials (UD-CCM). UD-CCM has a strong history of transitioning the extensive knowledge base of the design, fabrication, performance

assessment and repair of composite materials both back to the government and to industry. The primary sources of UD-CCM funding are large programs with federal agencies – building on the Center's strategic alliances with our industrial partners – but 19 percent comes from industrial contracts. Since the Center's establishment in 1974, CCM has collaborated with about 150 companies in addition to on-going close collaboration with the U.S. Government's Army and Naval Research Laboratories.[12]

In the United Kingdom, the concept of the entrepreneurial university is being pushed further. At the Imperial College of Science, Technology, and Medicine in Kensington, a technology transfer company – Imperial College Innovations, Ltd. -- works to maximize the value of intellectual assets by supporting entrepreneurial spin-off companies. Owned by the College, the company provides spin-off company assistance including intellectual property guidance, company start-up management blueprints, networking, and seed funding. IC Innovations currently spins off about one new company a month.[13] Recent U.K. government policies to support industry-government-university collaboration have included provision of seed funding in the late 1990's for business development.[14]

From the perspective of U.S. universities, it is essential that the government continue to fund basic research. This appears to be true also for European and Canadian universities as well. While industry is interested in collaborative relationships, it prefers to use its scarce resources for applied research into technologies that may prove profitable. Basic research is vital to discover the new material or process that will permit applied research to occur. Entrepreneurial universities may be reaping dividends from their collaboration with industry, but those dividends are not sufficient to fund basic research on a self-sustaining basis.

<u>U.S. Basic Research for the Future.</u> By the end of the 20th century, U.S. industry was spending about twice as much as the federal government on research. However, the federal government remained the largest provider of basic research funds. In FY 2003, research and development spending by the government should increase significantly although these increases are largely in defense, anti-terrorism and health expenditures. Professional groups, including the U.S. Commission on National Security/21st Century, concluded that the U.S. Government has not taken a broad, systematic approach to investing in science and technology research and development and thus is at significant risk of being eclipsed by other countries.[15] Although current priorities preclude additional funds across the board for research, more funding for basic sciences is needed.

<u>Maintaining Basic Industries in the U.S.</u> The economics of production in other countries and global oversupply have left most metal industries in financial difficulty. In particular, the steel industry required specific action by the government using the nation's diplomatic, political and economic power to restore market forces to world steel production. The Federal Government's role included diplomatic efforts to encourage reduction of excess global steel capacity and elimination of market-distorting subsidies. Domestically, the International Trade Commission (ITC) found that increased steel imports were a substantial cause of serious injury to our domestic industry and imposed temporary safeguards to help give America's steel industry and its workers the chance to adapt to the large influx of foreign steel.[16]

Essay 1

STEEL – MAINTAINING GLOBAL COMPETIVENESS

Antebellum steel producers created the United States' first modern industry. Mastery of steel production on a large-scale in turn enabled the creation of a manufacturing-based economy. A labor- and capital-intensive process, steel-makers smelt and refine metal from iron ore and/or scrap. The molten metal is formed into semi-finished shapes before it is rolled, drawn, and extruded to make sheet, rod, bar, tubing, and wire products used throughout the economy. The U.S. steel industry has two major sub-sectors:

- ***The carbon and alloy steel industry*** employs about 115, 000 workers producing over $50 billion in steel annually. The industry includes large *integrated* steel producers and *minimills*[17]. *Integrated mills* make steel from ores and minerals, but now also use state-of-the-art, electric arc furnaces (EAFs – also used in *minimills*) that smelt scrap steel. *Minimills* were the early adopters of EAF technology, starting in the 1960's and now constituting about half of US production. Today, many *minimills* are larger than the more traditional *integrated* mills. EAF's require a much smaller initial capital investment, spurring *minimill* proliferation. Other significant *minimill* competitive advantages are lower labor costs[18] and lower environmental impact. The carbon and alloy industry accounts for about 98% of total domestic steel shipments by weight.
- ***The specialty steel industry*** employs some 25,000 workers producing $8 billion annually in high technology, high-value stainless and other special alloy products. Formulated for use in extreme environments demanding hardness, durability, strength, and resistance to heat, corrosion and abrasion, these specialty alloys include stainless steels, tool steels, electrical steels, and super alloys. By weight, specialty steel accounts for 2% of production, but over 14% of the total value.

Steel in the Information Age. Though uneven in their implementation, steel companies have leveraged information technology in nearly all aspects of their industry, improving both product quality and worker productivity. Steel shared in the productivity gains afforded by computerized office systems – important, given the scale of the enterprise and the vast quantity of information formerly processed manually. Steel industry investments in automation and information technology changed the nature of many production jobs, while eliminating or reducing the demand for others. For example, computers allow one worker to perform duties that previously took the efforts of several. However, complex multi-functional computer-controlled equipment often requires different skills and more training than the simpler machinery it replaces.

This workforce capitalization created extraordinary productivity gains, reducing man-hours per ton from 10.5 in 1980 to an average of 2.2 in 2000, making some U.S. firms the world's lowest cost producer for some types of steel. But it also created problems; among them displaced workers and an increased need to compete for information skills – among the most constrained sectors of the labor force. Retraining of some displaced workers is possible, but as it modernizes, industry wants government to bear retraining and other costs of a shrinking workforce, as well its legacy of pensions and health care.

Global Perspective. The bane of the steel industry is global overcapacity. International steel production exceeds world market needs by as much as 40%. Competition for markets is fierce, creating extremely low prices for bulk steel. Domestic steel prices in the last quarter of 2001 were at their lowest levels in 20 years, contributing to corresponding financial losses. Despite record productivity, U.S. steel producers have difficulty competing with foreign producers in both domestic and export markets. Since 1998, firms accounting for thirty percent of U.S. steel-making capacity have filed for bankruptcy. Domestic steel producers cite the following factors as contributing to their lack of viability:

- Foreign industries gain advantage by government subsidization.
- Foreign steel dumping into the U.S. market below production cost.
- High cost of meeting U.S. environmental standards.
- Legacy costs of retirement and health care for 600,000 pensioners – costs not necessarily borne by industry overseas.

The U.S. International Trade Commission investigated steel imports and found that imports cause serious injury to the U.S. steel industry. In response, President Bush imposed a three-year schedule of tariffs of up to 30% on a wide range of imported steel products. This action creates opportunity for industry to reorganize to compete, perhaps without placing an undue burden on U.S. steel consumers.

Steel as a National Security Asset. DoD uses about 7.5 million tons of steel annually, costing over $ 2.6 billion. This includes military hardware, construction, maintenance and other support applications including family housing, but omits steel purchased by private sector contractors. Though DoD uses domestic sources for military-unique alloys, such as that used in submarine hulls, the military consumes less than 3% of domestic steel production by value. This fact, combined with a global steel glut, begs questioning steel's real strategic value. Given that the U.S. is already dependent on foreign steel – we don't make as much as we use – the question is one of degree – not if, but how much dependence is acceptable for national security?

The national security value of steel is best considered on a broad scale, to include both steel's major role in the economy as well direct and indirect military needs. Because nearly every aspect of the economy uses steel and its industry and unionized employees command national attention, its entire impact must be measured in this context. Steel's value is as much political as empirical; therefore, numbers are interesting, but not decisive. The fundamental questions are "does the U.S. need to produce steel even if it's uneconomical to do so," "to what extent will government protect industry from its own inefficiencies," and "to what extent can the U.S. force a level global playing field?" Tariffs partially address the last two questions by leveling the U.S. market and providing industry with a strategic pause that offers industry a chance to revitalize itself.

Conclusion. Steel remains vital to the United States economy and its military. Steel can be replaced in individual applications, but there is no economically suitable substitute for steel at the macro level. Therefore, though not scarce, it is strategic, as long as the material fabric of American society is woven of steel. Fortunately, the U.S. steel industry has improved its productivity, processes and products through new technological capabilities, making parts of it world class. However, it struggles with global competition compounded by excess capacity. Tariffs will only buy time to reorganize –

American steel producers must find a profitable niche or collapse when support ends, if not before. But when the next act starts, the U.S. will have access to all the steel it needs, and, thanks to information technology, plenty of it will be American.

Written by Lt Col John Kidd, USA and CDR Jim Churbuck, USN

Essay 2

NANOTECHNOLOGY:
THE NEW MULTI-DISCIPLINARY FRONTIER OF SCIENCE

Nanotechnology is an emerging multidisciplinary field of science that manipulates matter at the molecular and atomic level to obtain multifunctional materials with properties significantly improved over traditionally manufactured materials. While scientists are only beginning to scratch the surface of this burgeoning field, nanotechnology promises to lead to the next global revolution. The National Nanotechnology Initiative (NNI) has spurred both international and domestic research efforts. Growing participation by government laboratories, government sponsored university research programs and corporate research projects will help achieve breakthroughs in revolutionary nanoscale manufacturing techniques. In the meantime, traditional manufacturing processes using nanostructured materials provide significantly enhanced performance. Proactive government policies will capture the economic, political and military advantages of nanotechnology.

What is nanotechnology? Mihail C. Roco, the National Science Foundation (NSF) official directing the National Nanotechnology Initiative (NNI), offers a fundamental definition. Nanotechnology deals with materials and systems having at least one dimension of about one to 100 nanometers that are designed through processes exhibiting elementary control over the physical and chemical attributes of molecular-scale structures. These materials and systems can be combined to form larger structures that boast superior electrical, chemical, mechanical, optical or computational properties.[19]

Multi- and inter-disciplinary nature. Nanotechnology integrates most every major research area. It incorporates chemistry, engineering, biology, materials science, physics, and information sciences and is extremely relevant to the progress of other overlapping technologies such as biotechnology, information technology and the digital revolution, as well as cognitive science.[20] Nanomaterials, nanoelectronics and nanobiotechnology are all finding common ground in the cross-disciplinary nature of nanotechnology. Materials scientists, mechanical and electrical engineers, and medical researchers are teaming up with biologists, physicists and chemists. Nanotechnology is creating the need to share knowledge, tools and techniques, and expertise at the atomic and molecular level. Moreover, the converging research fields, with the help of increasingly powerful computing capability, are expanding nanotechnology into more innovative application fields.[21] Scientists believe major scientific disciplines and industry will converge in nanotechnology.

The National Nanotechnology Initiative (NNI). The potential of nanotechnology has captured the imagination of scientists in industry, academia and government. The Clinton Administration established the NNI in fiscal year 2000 to manage and guide the nanotechnology research effort. Funding has increased each year including fiscal 2002

even though President Bush proposed funding cuts to most other federal agencies that support research and development. The largest share of NNI goes to the National Science Foundation (NSF), which coordinates the entire initiative across nine federal agencies.[22] More than 30 universities created nanotechnology research centers and interdisciplinary groups; fewer than 10 existed two years ago.[23] The list of companies investing in nanotechnology research includes many industry leaders including Hewlett-Packard, IBM, Siemens, Dupont, 3M and Dow.[24]

International R&D competition. NNI has stimulated nanotechnology activities in other countries as well. At least 30 countries have initiated research activities, and several countries have adopted coordinating offices at the national level similar to NNI.[25] The Republic of Korea put forth an ambitious plan in July 2000 to achieve world-class nanotechnology competitiveness in the next 10 years. It includes establishing a $100 million large-scale nanofabrication center with full professional staff, for design, fabrication, integration, business development and education programs slated to include overseas collaborations.[26] The worldwide government nanotechnology R&D investment has increased by a factor of 3.5 between 1997 and 2001, with the US, Japan and the European Community dominating current R&D efforts.[27] The U.S. risks falling behind its international competitors if it fails to sustain broad based funding.

Area	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
W. Europe	126	151	179	200	225	
Japan	120	135	157	245	550	
USA	116	190	255	270	422	579
All Others	70	83	96	110	380	
Total (% of 1997)	**432 100%**	**559 129%**	**687 159%**	**825 191%**	**1,577 365%**	

Table 1. International Nanotechnology Research and Development Funding (US$ M)[28]

Awesome economic potential. Nanotechnology has the potential to generate huge economic dividends. In medicine and pharmaceuticals, the National Institutes of Health is developing advanced treatment options.[29] Department of Energy research in materials science creates super strong aluminum composites.[30] The National Aeronautics and Space Administration (NASA) is pursuing nanotechnology in its primary mission of space exploration.[31] Nanocomputers, expected to replace silicon computer chips, could provide unparalleled computing power.[32] Rudimentary forms of commercial nanotechnology products are already available; however, the challenges of creating affordable manufacturing capabilities, as well as establishing market demand remain.[33]

Questionable future. Sizable nanotechnology budget increases over the last four years have drawn criticism because some of its research objectives may not be achieved for up to twenty years. Furthermore, industry is reluctant to finance research programs that may not yield near-term profit and is relying on the federal government to take the lead in developing the future nanotechnology workforce.[34] A 2001 study by the American Society of Mechanical Engineers (ASME) forecasts a harmful “workforce shortfall."[35]

Conclusion. As the world experiences the first ripples of the nanotechnology wave, it is apparent that breakthroughs in nanotechnology will lead to a scientific and global revolution at least as profound as the industrial or information revolutions. Industries from biotech to microelectronics, chemistry to engineering and national security are realizing that nanotechnology can completely transform their strategic environments.[36] The nations that can effectively leverage the enormous potential of this emerging technology will be the global leaders of the 21st century.

The political debate concerning America's technological advantage must embrace nanotechnology. Of particular importance at this stage is refinement in our investment policy to identify the most promising venues and to redirect resources into those programs. The Advanced Concept Technology Demonstrators (ACTD) should be used to support endeavors to develop advanced manufacturing processes incorporating nanotechnology. Crucial to this effort is an accurate analysis of the technology readiness.

Finally, the Department of Defense (DoD) needs to begin planning the transformation resulting from the incorporation of nanotechnology. A lighter, more agile force is of little use without the policies and organizations to take advantage of the change. Despite the significant investment in legacy systems, DoD cannot afford not to evolve and adapt to the nanotechnology revolution.

Thus, the question is no longer when the technology will become available, but rather who will take the lead and reap the benefit. The promise of nanotechnology is virtually unlimited. It will revolutionize the strategic environment and materials industry in particular. Through informed public debate, acceptance of appropriate risk and forward-looking policies, we can maximize the benefits of the imminent nanotechnology revolution.

Written by Lt Col John J. Gomez, USAF and CDR Sidney Kim, USN

Essay 3

KNOWLEDGE MANAGEMENT IN THE MATERIALS INDUSTRY

In the materials industry broadly, knowledge management is not yet an acknowledged business practice. Most companies do not have Chief Knowledge Officers (CKO), although many do have Chief Information Officers (CIO) who concentrate solely on IT and its application. In practice, however, many companies do practice some degree of knowledge management, particularly if they wish to maintain their competitive advantage. While technology is only a tool for managing intellectual assets, many companies fall into the trap of equating a greater reliance on technology with knowledge management. The imperatives of the global marketplace increasingly drive the mature metal industries – steel, aluminum, and titanium – to innovate in production and application. They gather information on global prices and production to track their own performance, but their capacity to manage intellectual assets is constrained by the fact that they are industrial producers.

The segments of the materials industry that are still maturing – polymer composites, metal matrix composites, ceramics – are riper candidates for adoption of knowledge management practices. In these segments, the vast majority of producers are privately held, small and medium sized businesses. Because of their size, they tend to

have streamlined management and smaller workforces. Very few have a CKO, but some of the largest do have a CIO. The smaller companies generally have one person – usually the president of the company – who wears multiple hats. In the most successful companies, the president successfully values the intellectual capital on hand and actively seeks to keep that capital up to date in order to remain competitive. Despite the lack of a formal knowledge management structure, most companies do share information either directly or through industry associations. These associations act as information clearinghouses for members, providing technical and business information on issues as diverse as the latest research, manufacturing breakthroughs and compliance with environmental regulations.

Knowledge management is more apparent on the research side of the materials industry. Universities, usually using government funds, undertake most basic research although there is some industry money provided. This research generally focuses on development of new materials as well as new manufacturing methods. Spurred by government initiatives to attract and retain scientists and to ensure continued research and development in areas of critical interest, universities, government labs and private industry have entered into innovative collaborative relationships. These relationships are often cemented by mutually favorable licensing agreements and technology transfers that result in commercialization of new materials and processes.

Sharing of information is critical in the research and development process. Researchers must know what others are pursuing, both for the pure science – ensuring pursuit of all avenues of inquiry – and for the encouragement of industry to put the technology into practice. While most of this knowledge-sharing is informal, using standard IT tools such as email and internet, there is also sharing of intellectual capital by means of sending individuals with particular knowledge assets to work together side by side for specified periods of time. Seminars, conferences and scientific papers also are useful tools for sharing information and getting feedback from others on the presumed value of the shared intellectual assets. These many collaborative methods lead to tangible evidence of knowledge-based assets – patents, trademarks, and documented research – but also enrich the intellectual property of the individuals who populate the labs and businesses.

In the emerging segments of the materials industry – biomimetics, MEMs, nanotechnology – there is a tendency to assume knowledge management is well entrenched because this segment is technology-rich and still very much in the research phase. Researchers around the globe are in constant communication about the latest discovery and development and possible avenues of research. This segment of the industry makes great use of computer modeling to further its research, but in most cases it must develop these models from scratch relying on the intellectual capacity of its workforce to generate even greater value by producing a model that then supports the research into these leading edge technologies.

When dealing with intellectual and knowledge-based assets and their management, information assurance is always a concern. While the term information assurance usually refers to the security of critical IT systems, it can also easily apply to protection of intellectual property. The obvious ways this happens is through the patent process for new processes and materials. Businesses also have proprietary information that may or may not be patented, but is considered critical for that company's competitive

advantage in a certain area. Once patented or declared proprietary, some constraints appear on the dissemination of ideas, materials and processes. These constraints are usually directed against external “threats” but can also be directed internally. From a knowledge management perspective, these types of constraints are understandable – indeed, they may be vital to give and maintain a company’s competitive advantage in a particular area. While political espionage has a long history, industrial espionage is also quite common. Companies must take steps to protect proprietary information and intellectual property in a manner that does not prevent sharing of other information.

Management of knowledge-based assets is clearly an increasingly common issue for successful organizations, particularly as the US economy completes its shift to a technology-based, service economy. As the US produces fewer and fewer widgets – relying on trading partners to provide more and more of them – it produces and leverages ever more intellectual property and capital. Tapping into those knowledge-based assets, ensuring they develop to their full potential and protecting them from those who wish to exploit them for other purposes will become a greater challenge in the future. Strong leadership is vital, whether or not the leader bears the title of the Chief Knowledge Officer. The title is less important than the function. Indeed, if the materials industry is any indication, companies that wish to succeed must demand that all members of their management team buy in to the idea that knowledge is not power but rather a powerful asset affecting the company’s bottom line.

Written by Deborah Malac, Department of State

Conclusion

In a technology driven world, certain materials will make essential contributions to a nation’s economic development and defense capabilities because they enable performance improvements that create a distinct competitive advantage. While the materials themselves are essential, they are also the product of a research system of systems. The system of systems seeks a capability, determines existing limitations and the possibility of overcoming them, and then assesses the available time and money required to achieve that capability. This process also helps quantify the risk associated with producing or exploiting a new or enhanced material. Indeed, it is the willingness to tolerate risk, to push the edges of what is possible and to respond quickly to promising developments that marks successful firms within the strategic materials industry.

The system of systems involves interactions between government, academia, and industry whose roles vary depending on the customer’s objective and the cultural and political operating environment. Government has traditionally funded basic research at both universities and its own facilities. Though some governments may divest themselves of their own research facilities, if government’s role is to promote technological progression, basic research funding must come from government – most of industry only funds research that can be quickly marketed. Except for niche producers, government is not a major customer in the materials market, so government must also expect to fund the applied research necessary to develop materials with advanced performance necessary to maintain superiority in defense applications or wait for a commercial need to impel production. Academia is well positioned to respond to either

industrial or government customers and is increasingly savvy in extracting value from their research and development activities, which have consistently expanded the capabilities of traditional materials as well as offering novel and exotic materials with revolutionary potential.

The horizon is full of exciting developments in materials science. Among the most promising of material trends is their improving versatility. "Materials of the 21st century will likely be smarter, multi-functional, and compatible with a broad range of environments."[37] This evolution is being speeded by information technology and multi-disciplinary approaches to research and development, which are increasing the sense of what is possible as well as providing the means to achieve it. Given a sustained national emphasis on technological development and sufficient research funding, the system of systems will continue to produce materials that enable strategically important capabilities for both defense and economic growth.

Endnotes

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16 Press Statement, Office of the Press Secretary, White House, 5 March 2002
17 The term "minimill" originated from their relatively small size as compared to traditional integrated mills.
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[25] Roco, M.C., International Strategy for Nanotechnology Research and Development, p. 6, 28 August 28 2001.
[26] Y Eugene Pak, "A Bid to Take the Lead," *Mechanical Engineering*, Vol. 124, Issue 1, Jan 2002, pp. 56-57.
[27] Roco, p.6.
[28] Ibid.
[29] A Paul Alivisatos, "Less is More in Medicine," *Scientific American*, Vol. 285, Issue 3, Sep 2001, p. 66. NIH is developing instruments capable of identifying the gene causing a disease, thus allowing precise diagnosis of the exact form of the disease present, and guiding treatment. Additional research into nanoparticles and nanospheres for drug and gene delivery is on going.
[30] Dietz, p. 37. Research conducted for the Department of Energy employs nanotechnology to create lightweight aluminum composite surfaces that are as strong as the best steel available. These materials will likely be used in engine blocks and automotive bodies.
[31] John DeGaspari, "Probing for Flaws," *Mechanical Engineering*, Vol. 123, Issue 10, Oct 2001, p. 73. NASA's Langley Research Center in Hampton, Va., is making use of nanotechnology to develop methods for nondestructive evaluation to support super lightweight, multifunctional structures. By precisely extracting, manipulating, and placing individual carbon nanotubes in next-generation aerospace materials, researchers will test for structural weaknesses in material structures. Carbon nanotubes have an electrical charge that can make them sensitive magnetic field sensors. By incorporating carbon nanotubes in specific areas of a sample, a high-resolution, lightweight, low-power consumption field sensor is created. The next stage is to test sensory capabilities of the materials and apply them to structures, a process that can take several years.
[32] Roco, p. 6. Million times faster than today's most sophisticated computer.
[33] Davey, Michael E., Congressional Research Service, Report for Congress, "RS20589: Manipulating Molecules: The National Nanotechnology Initiative," pp. 1-2, September 2000.
[34] Ibid. While nanotechnology may hold great promise, some scientists contend that the field's definition is too vague and that much of its 'hype' may not match the reality of present scientific speculation."
[35] Dietz, p. 37. The ASME study states, "Indeed, the unique characteristics that allow us to work at the molecular level and enjoy the benefits of nanotechnology also expose a potential lack of knowledge that could cause a harmful workforce shortfall." This potential shortfall mirrors the difficulties encountered by the computer-related industry causing companies to import temporary workers from overseas.
[36] Uldrich, p.22. According to Harvard professor George Whitesides, "It's important to stay on top of the industry... because if you bet wrong, you can be out of business in a very short time." In 1999, The Institute of Global Studies surveyed executives in leading Fortune 1000 companies about the emerging area of nanotechnology. Fewer than 2% could accurately define the term, and only another 2% had ever heard of nanotechnology. Once the concept was explained to the executives, fully 80% agreed that nanotechnology was relevant to their respective industries. Many undoubtedly have followed up and are making the necessary changes and investments to grow, prosper, and profit from the advances that are emerging on an almost daily basis. This demand in turn will further fuel the rapid development of nanotechnology.
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